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COMMENT DRAFT[*]

The Economic Case for Dedicated Unlicensed Spectrum Below 3GHz

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Abstract[1]

There is general agreement that traditional mechanisms for managing radio frequency (RF) spectrum are inefficient and in need of significant reform. Many, if not most, of the economists who have considered the issue appear to concur with the view that increased reliance on market forces would enhance efficiency, and support assigning spectrum via transferable, flexible licenses, especially when spectrum is perceived to be scarce.[2] The FCC's Spectrum Policy Task Force (SPTF) has endorsed this perspective, advocating only limited use of dedicated unlicensed for lower frequency spectrum (below 3GHz).[3] Unfortunately, the economic case for additional dedicated unlicensed spectrum in lower frequency bands has not been adequately stated. The goal of this paper is to redress this deficiency and lend economic support to the case that has already been made by an active minority of knowledgeable legal and technical experts in support of the unlicensed model.[4]

This paper explains the economic arguments in favor of allocating additional dedicated unlicensed spectrum in the lower frequency bands below 3GHz.[5]

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I. Introduction

The expansion in wireless services is one of the most important trends that has transformed the Information, Communications and Technology (ICT) sector during the last decade. Mobile telephone services changed from being a premium service for the elite, used mostly from cars, to a mass market communication service that can be used anywhere. Over the same period, the growth of the Web, email, and the Internet brought data communication services to the mass market for the first time. Now, with the emergence of wireless broadband data services, the two worlds are converging. This convergence will help drive another cycle of investment, innovation, and economic growth.

Wireless enables mobile computing and ubiquitous connectivity, thereby improving old services and creating opportunities for new ones. Progress in sensor networks, information technology in biotech, multimedia integration, and "GPS" location-based services all depend on wireless technology. Wireless also offers one of the best hopes for increased competition for wireline services. Direct broadcast satellite and new digital terrestrial broadcasting compete with coaxial-cable TV, while mobile telephony and wireless local loops (WLL) compete with fixed line telephony. Continued growth and innovation in wireless services is critical to the health of the ICT sector, and hence, to the overall economy.

While "wireless services" encompass an incredible diversity of uses, technologies, and markets, one commonality is that they all depend on access to the radio frequency (RF) spectrum. The traditional model for managing spectrum for commercial use has been based on a licensing regime that grants licensees limited and restrictive-use rights to a specific frequency band in a geographic area.[6] Historically, the license regime imposed restrictions on the services that could be offered, the technologies that should be used, and the transferability of license rights.[7] In light of advances in wireless technology and the evolution of markets for wireless services, consensus is emerging that the traditional model for managing spectrum is grossly inefficient.[8] It has impeded innovation and investment in new technologies. The regulatory restrictions have artificially constrained opportunities to redeploy spectrum to higher value uses, to offer new services, and to adopt technologies that would utilize spectrum more intensively. The net effect has been to accentuate a perception of acute spectrum scarcity. The question is not whether spectrum management is in need of reform, but rather *how* it should be reformed.

Much of the focus has been on increasing the economic role of market forces in regulating how spectrum is allocated and used. There has been increased pressure to liberalize licenses and facilitate the emergence of secondary-markets for spectrum.[9] While this represents an important direction for reform, it is generally associated with continued reliance on a regime based on exclusive-use licenses to specific frequency bands. While the licensing model remains important, it is not the only model for managing spectrum.

This paper makes the economic case for allocating additional lower-frequency spectrum for dedicated "unlicensed" use (below 3GHz). The market success of services operating in current allocations of dedicated unlicensed spectrum, the potential for unlicensed spectrum to support new and innovative technology and business models, and the need to "future-proof" regulatory policy make it desirable to allocate additional spectrum for unlicensed uses.

The rest of this paper is organized into five sections. Section II explains why there is renewed interest in the unlicensed model, and Section III explains why spectrum below 3GHz is special. Section IV clarifies what is essential about the "unlicensed" model and addresses several potential misconceptions that may confuse how it differs from the licensed approach. Section V focuses on the arguments in favor of relying on a regime of exclusive licenses instead of unlicensed use for lower-frequency spectrum, and explains why an additional allocation for unlicensed use would be beneficial. Section VI concludes.

II. Why the interest in unlicensed spectrum?

Traditional spectrum management based on exclusive licenses to narrow frequency bands has been justified, in part, on the basis of hundred-year-old radio receiver technology.[10] Early receivers were limited in their ability to tune and separate desired signals from background noise, which might include signals from other transmitters. The exclusive licenses granted the licensee the right to deny use of the spectrum to other transmitters operating in that frequency band.[11] This was intended to protect the licensee's service from interference, but it also allowed the licensee to exclude shared use even in situations where such use would not interfere.[12]

Over time, technology has evolved in ways that make it possible to build much more efficient and dynamically-responsive (intelligent) radio systems that can allow many users and uses to simultaneously share the same frequency bands. Technologies like smart antennas, spread spectrum modulation, and cognitive (software) radios[13] make it feasible for transceivers to dynamically change their frequency, modulation, or power levels to enable more efficient and intelligent spectrum sharing.[14] The traditional logic that exclusive frequency licenses are needed to manage "interference," has been significantly undermined by technical progress and the evolution of wireless markets. For example, advances in signal processing technology (*e.g.,* multi-user detection theory) and cooperative networking (*e.g.,* ad hoc networks or grid computing) can exploit the fact that there are multiple signal sources sharing the same frequency bands to improve reception gain.[15]

The increased interest in the unlicensed model has been prompted, in part, by the dramatic growth associated with wireless Local Area Networks (WLAN).[16] For example, the rapid growth of WiFi – a WLAN technology – demonstrates the important role that unlicensed can play in the evolution of wireless services.[17] WiFi services operate in the 2.4GHz unlicensed band that is shared with cordless phones, microwave ovens, and a variety of other uses.

Considering the sad state of the ICT sector in recent years, it is especially noteworthy that 22.7 million WiFi units worth $1.7 billion were sold in 2003, reflecting three-digit growth for each of the preceding two years.[18] Although the reach of a WiFi base station is limited to a few hundred feet, the proliferation of WiFi-based public "hot spots" in government buildings, airports, hotels, coffee shops, and other public areas make it increasingly possible to cyber-forage for a wireless broadband connection.[19] According to Gartner Dataquest, public "hot spots" are projected to grow tenfold from almost 15k in 2002 to over 152k by 2005.[20] Pyramid Research predicts there will be 707 million WiFi users generating $21 billion in service revenues worldwide by 2008.[21] In addition, many end-users are using WiFi to extend the reach of their fixed broadband service throughout their homes thereby enhancing the usability of broadband Internet access and providing opportunities for new types of consumer-grade networked appliances. In many cases these home WLANs and sponsored hot sports are supporting open access to the general public via "freenets."[22]

In light of this remarkable growth, it is worth remembering that as recently as five years ago, most analysts expected wireless broadband data access to be delivered by mobile telephone service providers over their "3G" networks. Although 3G services are now available in some markets, it has taken longer than expected, the coverage is more limited, and the bandwidth slower than originally touted. Additionally, carriers have not harmonized on a common "3G" standard and equipment prices remain high. While mobile carriers will remain key participants in the broadband wireless world, they are no longer the only player. Five years ago, WLANs and 3G services were viewed as addressing very different market needs. Now, it is clear that these services can be both complements *and* substitutes.[23] Equipment makers and service providers are now busily trying to integrate 3G and WiFi services.

Other technologies like WiMAX (802.16) are extending the capabilities of WLAN-like technologies to cover metropolitan-sized areas, higher bandwidths, and better congestion and security management capabilities in order to make them more suitable for adoption by public communication service providers. These updated version of "MMDS"-like technologies may be used as a platform for delivering WLL access services. The use of such technologies offers an alternative to and competing use for spectrum that might otherwise be used by mobile telephony providers for their 3G (and after that, 4G) services, or by over-the-air broadcasters to deliver interactive multimedia content. At the same time, technologies like ultrawideband (UWB) are challenging the very basis for managing frequency in the form of exclusive licenses. UWB applies spread-spectrum techniques to enable high bandwidth transmissions to efficiently share a broad frequency band without destructive interference. While current development efforts are focusing on the use of UWB as a short-distance wireless-cable substitute (*e.g.,* to provide wireless connectivity for home entertainment systems),[24] UWB could be used also to support wide-area broadband communications.

The future wireless world will consist of a heterogeneous mix of overlapping and partially integrated wireless networks and technologies. Legacy technology will continuously mix with a continuous stream of new technology.[25] Short-range networks will mix with longer-range networks. There will be networks limited to an individual's personal space (WPANs), networks that reach tens to hundreds of feet in a home or office (WLANs), and networks that extend tens of miles (WMANs). Some will consist of one or only a few base stations, while others will integrate many base stations providing service over a wide-area. Some will provide mobile communication services at automobile speeds, others at walking-speeds, and others only to specific fixed locations (*e.g.,* WLL). There will be networks that support data rates for traffic that is low speed (control, sensors), intermediate speed (Web browsing, email, or telephony), and high speed (high-resolution video or remote disk sharing). Sometimes these capabilities will be provided over an integrated network and other times over separate networks that may or may not communicate with each other. These may be owned by an end-user, a single service provider, or require traffic to be handed-off across infrastructure owned by multiple end-users and service providers.[26]

The business cases for delivering these wireless capabilities to end-users will vary by technology and application. For example, WPAN and WLAN technologies to interconnect consumer appliances may be bundled and sold as consumer equipment. Wider-area services based on 3G or 802.16 technologies may be deployed via a service provider model. In the former case, it may seem more natural to rely on an unlicensed model because the devices may be expected to be used more often in a non-coordinated, standalone fashion (*e.g.,* within a single home). Whereas a licensed model may seem more natural to support a service-provider model used to provide wide-area communication services over a wireless network involving many base stations covering a large geographic area. In the case of a Bluetooth-enabled headset or MP3 player or a UWB-enabled home entertainment hub, it is more likely that interference issues – if they arise – can be locally managed (*e.g.,* if a cordless phone is interfering with use of the home WLAN, then walk a few feet away). In contrast, service providers may be reluctant to invest the millions of dollars that are required to build a wide-area carrier network without the protection against future interference that an exclusive license provides.

While the linkage between range of operation, equipment/service provider models, and unlicensed/licensed spectrum is valid to a point, it is also overly simplistic. As the competition between WiFi and 3G demonstrates, technologies thought to address one set of needs may be used in another context, creating additional opportunities for technologies to compete with and complement each other. The convergence of computing and communications, which is pushed still further by the growth of wireless, makes it more difficult to define where the network "edge" is and what functionality should be included in equipment versus networks.[27] At this stage, it is far from clear which technologies will work best with which business and regulatory models to serve which user needs. In all likelihood, there will be a mix of models and this is healthy.

The need for a mix of regulatory models has been recognized by policy-makers. For example, the Spectrum Policy Task Force concludes that "no single regulatory model can or should be applied to all spectrum," (page 4) however they also argue that in the lower frequencies (below 5GHz), that the FCC "should focus primarily, though not exclusively, on using the exclusive use model" (page 38).[28] Before examining the economic basis for the bias in favor of a licensing regime, it is important to understand why spectrum below 3GHz is special and therefore needs to have additional spectrum allocated to unlicensed in order to properly respect the Task Force's worthwhile goal of promoting diversity in the regulatory models employed.

III. Why lower frequency spectrum is special

While technology is making it more feasible for spectrum at different frequencies to support similar services (and hence act as substitutes), there are important differences in the usefulness of spectrum at different frequencies. The chief technical advantage of using lower-frequency spectrum is that lower-frequency signals propagate more easily through the air and are more tolerant if there is not direct line-of-sight (LOS) between the transmitter and receiver.[29] Also, the electronics associated with operating at lower frequencies are less expensive.[30] Finally, there is simply much more spectrum available in higher frequency bands.[31]

Moreover, because of its attractiveness for offering particular services (*e.g.,* wide area communication services),[32] its limited abundance, and legacy technology issues,[33] the lower-frequency spectrum is much more crowded with incumbents than is higher-frequency spectrum. Over time, the frontier of usable RF spectrum has moved to ever higher frequencies as improvements in digital technology have made it increasingly viable to digitize and process higher frequency signals. These advances support viable communications using lower power signals in noisier environments, with improved non-LOS performance, and over longer distances (*e.g.,* smart antenna design) than was previously possible. While this has made it feasible to locate services in higher frequency bands than before – and thereby relaxed constraints on the supply of available spectrum – demand for lower-frequency spectrum has also increased. The changes in technology have not changed the physics of RF transmissions.

The technical "advantages" of lower-frequency spectrum depend on the intended application. For example, the longer propagation performance may be undesirable if the goal is to control interference by limiting the effective transmission distance. Thus, if one's goal is to interconnect entertainment system components within the home with high-bandwidth (data rate) channels that do not extend outside the home (potentially causing interference with other uses of the spectrum), using higher-frequency spectrum may be preferable: the benefits of spectral abundance are not offset by reduced propagation distance.

Alternatively, if one wants to go longer distances at high data rates then higher frequencies may also have advantages. For example, it is easier to concentrate a high data rate signal into a focused narrow beam at a higher frequency and this may also allow one to operate at a higher power (*e.g.,* microwave point-to-point services).

The benefits of lower-frequency spectrum are most apparent if one's goal is to support two-way, narrowband, communications over a wider area (measured in miles instead of hundreds of feet) where non-LOS operation is important. Classic applications here include mobile telephony service (*e.g.,* 2G/3G) and WLL (which includes MMDS and 802.16 technologies). On the one hand, the longer propagation characteristic means that fewer cell sites may be used if the service is supported at a lower frequency. These savings can be substantial. For example, Wanichkorn and Sirbu (2002) estimated the costs of deploying modern fixed wireless local loop systems based on second-generation MMDS technologies. They found that a system operating at 2.6GHz (current spectrum for MMDS) would require twice as many cell sites as one operating at 700MHz (UHF), which would result in system cost savings of 17%.[34] On the other hand, non-LOS operation can enhance usability (*e.g.,* a mobile phone works when in pocket or inside buildings) and lower installation costs.[35] Additionally, with the kind of antennas used in today's handheld devices, the signal will go farther at lower power at a lower frequency.[36] This can help conserve battery power which is important in its own right.

While the benefits of longer distance propagation, non-LOS, and potentially greater power conservation are readily apparent for certain classes of applications (*e.g.,* control networks, short message data services, and voice communications), much of the interest in new wireless services is focused on broadband applications. For such applications it may be preferable to locate these in higher frequency channels, in any case. While true, this is not an argument against additional dedicated unlicensed spectrum. Even if wide area, narrowband communication services do end up dominating most of the spectrum below 3GHz, this does not mean that the principal mode for managing such spectrum should be via exclusive licensing.

In any case, today a substantial chunk of prime lower-frequency spectrum is currently occupied by incumbent licensees that offer "broadband" services. Traditional over-the-air radio and television broadcasting in the AM/FM and VHF/UHF bands use valuable lower-frequency real estate for which alternative higher-frequency distribution media are already available (*e.g.,* coaxial cable television and direct broadcast satellites deliver many more programming channels without using lower-frequency spectrum). Partially relocating these services to higher frequency channels or conversion to more efficient broadcast transmission technologies would free up additional commercial spectrum for other uses that currently lack viable alternatives, *including* allocating additional spectrum for dedicated unlicensed use.

Finally, the debate over unlicensed versus licensed is not as important at higher frequencies precisely because spectrum is relatively more abundant. It can be allocated to both licensed *and* unlicensed commercial uses. Moreover, because higher-frequency signals travel more nearly in straight lines, an exclusive licensing regime could be based on point-to-point licenses.[37] Because the signals travel in a "pencil beam" (*e.g.,* a wireless fiber substitute), it is feasible to award a large number of non-interfering, exclusive licenses in a small geographic area.[38] If there are an infinite number of licenses available, then the licensing regime is closer to an equipment certification regime, like, for example, the Part 15 rules which govern operation in unlicensed spectrum today.[39]

This paper focuses on the need for spectrum reform to allocate additional dedicated spectrum below 3GHz precisely because this spectrum is highly desirable and its allocation is contentious. While the "scarcity" of spectrum is debatable, it is clear that regulatory policy can make spectrum scarce when it might otherwise not be.

IV. What's the real difference between licensed and unlicensed spectrum?

The preceding discussion has explained why advances in wireless technology and markets have increased pressure to reform spectrum management, and have increased interest in the unlicensed model. It also explained why spectrum below 3GHz is special. Before explaining the economic arguments in favor of allocating additional spectrum to unlicensed, it is worthwhile dispelling some potential misconceptions regarding the differences between the licensed and unlicensed management regimes.

A. Dedicated unlicensed is consistent with liberalized, flexible licensing

More spectrum for unlicensed does not mean less spectrum or less flexibility for licensed uses. The case made here is fully consistent with increased liberalization of spectrum policy and with the arguments by economists that efficiency would be enhanced if non-market-based restrictions on how licensed spectrum is used were relaxed.[40] Policies which facilitate the secondary trading of licenses will help direct spectrum to its highest value uses and will relax artificial (regulatory-induced) spectrum scarcity. Barriers to entry for new competitors, technologies, and services would be reduced. And, the opportunity cost for accessing spectrum would be reduced. In making the case for additional dedicated unlicensed spectrum, this paper presumes that the licensing regime will be reformed to eliminate inefficient regulatory constraints and to increase the role of market forces in determining how spectrum is allocated and used.[41] However, the case for allocating additional spectrum for dedicated unlicensed is even stronger if progress towards liberalizing rules for the use of exclusive licensed spectrum is limited.

Allocating additional spectrum for dedicated unlicensed use need not mean less spectrum for licensed uses.[42] There is frequency available to promote both regulatory models in the highly desirable lower frequency bands. Allocating an additional 100 to 300 MHz for dedicated unlicensed use below 3GHz would dramatically expand the available spectrum for unlicensed use, while leaving exclusive licenses the dominant model for managing commercial spectrum.[43]

Finally, it is worth noting that adopting a regime of dedicated unlicensed spectrum does *not* imply more regulation than does management under a liberalized license scheme. First, if the spectrum is not congested, then even the minimal regulatory oversight of issuing licenses can be avoided under an unlicensed regime. Complete deregulation would be the extreme version of an unlicensed regime.

Second, if congestion does occur, some sort of regulatory mechanism to reconcile and enforce conflicting claims will be needed regardless of whether the management regime is unlicensed or licensed. Congestion management in unlicensed spectrum could be via an access etiquette or protocol, through market pricing, or through some sort of administrative oversight. The administrative oversight could be via the courts (e.g., potentially, a specially-constituted "spectrum court"[44]) or via a regulatory agency such as the FCC, as is currently the case. These same options are available under a regime of exclusive licenses, and do not require adoption of exclusive licensing for implementation.

Although it may seem more natural to manage unlicensed spectrum through an access etiquette, there is no reason why the government could not either manage a real-time market, or outsource such management to a band manager for a fee. The band manager does not have to have an exclusive license to be induced to manage the spectrum efficiently.[45] The creation of such a market does not necessitate exclusive licensing, as I explain further below. Alternatively, if a protocol approach is used, this does not mean that the FCC has to choose the protocol. Its selection could be left to a private standards development organization (*e.g.,* IEEE). Finally, while it is beyond the scope of this paper to make a specific recommendation regarding how dedicated unlicensed should be managed, there are a number of proposals that might be considered, ranging from a modified version of the Part 15 rule framework that is currently used to regulate use in the ISM unlicensed band to some new set of "rules of the road" or a technical standard.[46]

Much of the support for exclusive licensing appears motivated by a desire to move regulatory control away from the FCC and towards deregulated markets or the courts. Prospects for realizing the goal of further deregulation would likely be enhanced if additional spectrum were to be allocated to dedicated unlicensed because this would help alleviate scarcity (reducing the opportunity cost for spectrum) and would potentially decouple and thereby defuse some of the opposition to reform.

Allocating additional spectrum for dedicated unlicensed may ease the transition to spectrum reform in several ways. For example, some of the opposition to flexible licenses is from those who support allocating additional spectrum for unlicensed uses. Such opposition would be ameliorated by the allocation of additional unlicensed spectrum. Other opposition to liberalized licenses is from those who oppose granting a windfall to incumbent licensees. Providing spectrum for dedicated unlicensed use would offset such a windfall by providing a substitute for the licensed spectrum (which will lower windfall profits to the extent that spectrum scarcity is reduced and provides a platform for competitive entry). Additionally, the perceived "windfall" might be reduced if incumbent assistance in making additional spectrum available for unlicensed were to be made part of the "bargain" with incumbents by which they might gain additional license rights. On the other side, much of the opposition to unlicensed comes from incumbents who fear secondary easements threaten their license rights. Dedicated unlicensed in another frequency band is less threatening than "in-band" unlicensed use via easements.

In summary, therefore, support for dedicated unlicensed does not mean more government control, more regulation, or less flexible licensing.

B. Unlicensed does not mean free access

The debate over unlicensed is sometimes confused with questions of what price to charge for spectrum. Implicit in the idea that spectrum ought to have a positive price is the notion that there are costs associated with allocating, managing, and using spectrum.

Because the RF spectrum is not "destroyed" when it is used, there are no costs associated with replenishing the resource.[47] However, a positive opportunity or use cost may arise when spectrum is scarce. The opportunity cost arises because spectrum that is used for one purpose may preclude use by another. The scarcity may be real – in the sense that two interfering uses may not be able to co-exist or share the spectrum at the same time – or artificial – as when there exists a regulatory restriction (which includes an exclusive license) that precludes another use even if such use could share the spectrum without interfering.[48] When multiple uses seek to share the same spectrum and there is "interference" then we say that the spectrum is "congested." Under such circumstances, the user of the spectrum imposes a "congestion" externality on other actual or potential users of the spectrum. This is a real cost of using spectrum that must be borne by society. Furthermore, whether the spectrum is priced or not, these economic costs are incurred. For example, they may be incurred in the form of reduced quality of service (*i.e.,* increased delays, higher bit error rates, or denial of service).

Spectrum costs may also arise associated with the need to address legacy issues (*e.g.* to clear spectrum from incumbents) or to cover spectrum management costs (*e.g.,* the costs of issuing and managing licenses or supporting a secondary spectrum market).

As long as there are costs associated with allocating, managing, or using spectrum, unlicensed spectrum is no more "free" than is licensed spectrum.[49] A key distinction over licensed versus unlicensed spectrum is not whether spectrum is "free," but rather how spectrum use is priced and charged for. An example of the classic licensed model is traditional mobile telephone service in which end-users make monthly payments to a service provider that increase with usage.[50] In contrast, the classic unlicensed model is of an end-user who purchases a WiFi-enabled device and then can communicate as much as she likes without paying any additional (future) fees for use of the service. In the WiFi case, the unlicensed spectrum was made available by the government for no "charge." Prior to the advent of spectrum auctions, the government did not seek to collect money for use of the spectrum.[51]

While these examples are clear, they are misleading because neither is necessarily bound to a particular pricing or business model. For example, a communication service contract could be offered over unlicensed spectrum (*e.g.* public "hot spot" vendors); or equipment vendors could capitalize spectrum charges in the initial purchase price (*e.g.,* the cost of acquiring spectrum for dedicated unlicensed use could be recovered via fees on equipment sales). Alternatively, equipment vendors can use leases and expected future purchases to amortize up front costs; or a service provider can shift future recurring charges to initial one-time charges.

The real distinction is not whether the licensee is a service provider or equipment vendor,[52] or whether costs are recovered via one-time charges or via recurring charges, but whether there is a private entity (business) that has a right to extract revenue from end-users as a condition for using the spectrum. The key distinguishing feature of unlicensed spectrum is that there is *no* grant of such a right. In an exclusive license regime, it is possible for the licensee to exclude other users for reasons beyond those related to interference management. These could include the desire to artificially restrict spectrum supply in order to extract scarcity rents or to protect or extend market power. For example, AM and VHF broadcasters opposed the allocation of spectrum for FM and UHF broadcasts because these promised to increase competition.[53] In contrast, in an unlicensed regime, the only restrictions against shared use arise as a consequence of the need to limit interference.[54]

Because the decision to adopt an "unlicensed" regime cannot eliminate real costs when they arise, it cannot make spectrum "free." However, by eliminating charges that might arise associated with artificial scarcity (arising from use of the exclusive use right), it should reduce the costs of using spectrum. This also means that if there are any fees for spectrum usage that these will not require prior negotiation of a contract with a service provider. Furthermore, it is expected that these will be small and will be associated solely with the need to account for only real costs associated with spectrum usage (*i.e.,* congestion costs or costs associated with setting up and managing use of the unlicensed spectrum).[55] Therefore, there is an implicit assumption that access to spectrum under an unlicensed regime will be *nearly* free to individual end-users.

C. Dedicated unlicensed is consistent with spectrum auctions.

Whether spectrum should be auctioned, and if so, how auction proceeds should be distributed is another issue that can confuse the debate over unlicensed spectrum. It is tacitly assumed that for auctions to be effective in eliciting bidders true valuations, the spectrum should be offered under exclusive use licenses. To really fit the theoretical ideal, these licenses should be perpetual.[56] Therefore, this would suggest that allocating additional spectrum to dedicated unlicensed is inconsistent with auctions. This is incorrect.

Over the last decade, spectrum auctions have provided a large source of funds for general government revenues. Proponents argue that these auctions efficiently allocate spectrum to its most efficient uses and provide a mechanism for the general public to benefit from any scarcity rents associated with spectrum. Opponents argue that the auctions have imposed a crippling debt burden on would-be providers and have siphoned off much-needed critical investment capital from the telecommunications sector, thereby slowing the roll-out of advanced services.[57]

While economists generally agree regarding the efficacy of auctions in assigning spectrum to its highest value uses, this could also be accomplished via secondary trading in exclusive licenses that may initially have been allocated by lottery.[58] Moreover, if secondary trading is not allowed, then auctions may fail to ensure that spectrum is assigned optimally over time. That is, even if the *ex ante* assignment (based on the best knowledge available to bidders at the time of the auction) is efficient, *ex post* changes in technology or markets may make a different assignment more desirable. Therefore, auctions are neither necessary nor sufficient to ensure that spectrum is efficiently allocated.

Auctions are also attractive because they provide a vehicle for capturing and reallocating any scarcity rents associated with spectrum use. For example, the promise of auction proceeds may induce government agencies and legislators to support reallocating additional spectrum for commercial use. If properly designed, an auction could also be used to reallocate/relocate incumbents efficiently and thereby ease the transition associated with spectrum reform.

Providing a practical mechanism for resolving transition issues is a key motivation underlying the two-sided "Big Bang" auction proposal of Kwerel and Williams (2002). Indeed, as Ikeda and Ye (2003) have suggested, auctions could be used to purchase additional spectrum for unlicensed use.[59] Such a plan could be incorporated into a "Big Bang" auction. Thus, auctions can be used to increase the supply of commercial spectrum and to re-direct existing spectrum to more efficient uses. When used in this way, support for auctions and for allocating additional spectrum to unlicensed are fully consistent.

The use of auctions to extract scarcity rents is much more problematic – but this is a problem both for licensed and unlicensed uses in that it artificially inflates the "cost" of acquiring spectrum. If the goal of the auction is to capture scarcity rents, policy-makers may seek to maximize auction proceeds which may induce them to restrict the supply of spectrum or limit competition in wireless services.[60] Capturing scarcity rents for the public coffers is sometimes rationalized as being consistent with the public interest because it provides a way for the general public to share in the benefits associated with spectrum use, not just the investors and customers of wireless firms. While the political attractiveness of such a policy is readily understandable, the implications are pernicious for telecommunications policy, especially at a time when policy-makers are seeking to promote investment in next generation communications infrastructure. Auction proceeds that are removed from the sector represent a tax on wireless services and reduce the funds available for investment.[61]

In summary, if auctions are used properly – solely as a mechanism to assign spectrum efficiently and to facilitate the relocation of incumbents – they are consistent with providing low-cost access to additional dedicated unlicensed spectrum. Of course, it is not necessary to use auctions to provide additional dedicated spectrum for unlicensed use, and as noted earlier, auctions are neither necessary nor sufficient to ensure that spectrum is efficiently assigned.

D. Dedicated unlicensed is different from underlay or overlay rights

Providing easements for unlicensed use of exclusive licensed spectrum is another policy option that is being widely discussed. Certainly, if such easements are granted it will provide a valuable opportunity for unlicensed users to access additional spectrum. There are two principle ways in which unlicensed easements may be granted: (1) as underlay rights; or (2) as overlay rights.

An underlay easement would allow secondary unlicensed users to share licensed spectrum as long as they remain below the noise floor established by the license. For some technologies, like UWB that operate by spreading their signal over a wide range of frequencies and thereby are able to transmit high data rate signals at very low power in any particular frequency channel, an underlay easement is especially attractive.

Alternatively, overlay easements (sometimes called "interleave" rights) allow secondary unlicensed use of spectrum during periods or in locales where the licensee is not using the spectrum. Location-aware (GPS) and cognitive radio technologies could be used to enable smart devices to modify their transmissions in order to dynamically share the spectrum with the licensed users. For example, by adopting a "listen before talking" protocol, an unlicensed user could detect if the spectrum is in use, and only transmit if it finds that the frequency is free.[62]

Both of these easements may be justified as desirable refinements of the exclusive use right that is implicit in a traditional license. With these easements, the exclusive use right is narrowed so as to more closely address only those situations where the licensee's use of the spectrum is threatened by interference. In effect, these easements reduce the likelihood that the granting of an exclusive use license will result in artificial spectrum scarcity either by its mere existence or by the way that it is enforced by the licensee.

While adoption of such easements would prove useful in supporting a wide-range of unlicensed operation, these are not an adequate substitute for dedicated unlicensed spectrum. First, implementation of unlicensed easements is quite contentious and has been widely opposed by incumbents. While there are many technical approaches to how these might be implemented, there is no general agreement as to the best technical solution.

With respect to underlay rights, the FCC is investigating defining a "frequency temperature" profile that would allow better account of how the need to protect interference may differ as one moves throughout the license territory.[63] The interference temperature concept is interesting, but there are a number of important technical and regulatory questions that need to be addressed. For example, how will the interference temperature be modified over time as technologies or services change? Will different temperature profiles be specified for each frequency license and will these differ by the services being offered? If so, that may amount to on-going frequency-specific regulation of the choice of technology and services and therefore mimic much of what has proven unsatisfactory with traditional spectrum management. Even assuming that this proves to be a viable mechanism for implementing underlay rights, that does not mean that incumbents will support its adoption.

With respect to overlay rights, there are even more problems and more diversity of opinion as to how to implement such rights and whether they are desirable. At one end of the extreme are technologies that rely on real-time dynamic frequency allocation. At the other end, there are modifications that would allow secondary use in rural areas where the licensee does not currently have infrastructure. There are important questions as to how overlay compliance would be enforced. Identifying and prosecuting infringing *intermittent* transmitters is likely to be quite difficult. The difficulties of implementation and enforcement will vary with the overlay/underlay strategy that is employed. In all cases, however, the licensee will have a valid fear that destructive interference will be more likely in their frequency band if the secondary use easement fails to be implemented correctly.

In contrast, with dedicated unlicensed, licensees in adjacent bands have no more reason to fear interference than if the adjacent spectrum were allocated under an exclusive use license. Therefore, allocating addition spectrum for dedicated unlicensed use may be easier in the face of opposition and may offer more "future proofing" with respect to dynamic technology changes. Exclusive license holders who have valid concerns about the threat easements pose for their current services and services they wish to add in the future may be likely to prefer supporting unlicensed use in dedicated spectrum, especially when the spectrum comes from someone else's piece of the pie.

Using easements to support unlicensed treats unlicensed as a secondary use.[64] This tilts the playing field towards licensed spectrum, thereby reducing the benefits from adopting an explicit approach to promote regulatory diversity. By providing for *both* additional dedicated licensed *and* unlicensed lower-frequency spectrum, the impact of regulation on the future choice of technology and the industry structure is reduced. The market can choose which spectrum model is more appropriate for supporting innovation and market growth. It may turn out that dedicated unlicensed spectrum is most useful as a testbed for experimenting with new services which find it necessary to migrate to licensed spectrum if the benefits of an exclusive license prove compelling. Alternatively – as certainly seems possible if not likely – we may find that the same vigor that has characterized competition and innovation in the unlicensed 900MHz, 2.4 and 5GHz bands extends to any new dedicated unlicensed spectrum.

V. Economic arguments in favor of unlicensed

In earlier sections, I explained why supporting dedicated unlicensed (1) is consistent with increased liberalization of exclusive licensed spectrum and does not imply increased government regulation of the unlicensed spectrum; (2) does not imply free spectrum, although it does assume that spectrum use costs will be neglible;[65] and (3) is consistent with using auctions to assign spectrum, although does not require that auctions be used. In addition, I have explained why additional dedicated spectrum above 3GHz or secondary use easements via underlay or overlay rights do not offer an adequate substitute for additional dedicated spectrum below 3GHz. In this section, I first characterize the economic arguments in favor of using exclusive licenses for virtually all lower-frequency spectrum, and then identify the flaws in these arguments. In the following, I am assuming that flexible licensing and secondary markets have been enabled. As noted earlier, if this is not the case, then the argument for allocating additional spectrum to dedicated unlicensed is even stronger.

A. Economic basis for supporting exclusive licenses

There are three principle economic justifications for relying on exclusive licenses: (1) spectrum scarcity; (2) investment incentives; and (3) interference management. The first justification views spectrum as an economic good and focuses on the role of markets in allocating that good. The second justification focuses on the need to provide users and providers with appropriate incentives to invest in network equipment and services. The third justification recognizes that even when spectrum is not "scarce," it may be necessary to coordinate user behavior in order to allow users to share spectrum without adversely impacting or "interfering" with each other.

These three justifications are closely interrelated and may each be viewed (loosely) as related to a slightly different notion of economic efficiency: "Spectrum scarcity" addresses *allocative* efficiency, which ensures that resources are directed toward their highest value uses; "Investment incentives" addresses *dynamic* efficiency, which ensures that resources are used optimally over time; and "interference management" addresses *productive* efficiency, which ensures that resources are not wasted (services are produced at lowest resource cost).

Each of these justifications rests on a common set of assumptions that are open to critique, and therefore, support consideration of an alternative management regime based on unlicensed use. These include assuming that: (1) spectrum is scarce; (2) markets offer the best mechanism for allocating scarce spectrum resources; and licenses are necessary for (3) markets to operate efficiently; (4) provide investment incentives; and (5) to manage interference. The following sub-sections explain why each of these assumptions are questionable. This discussion rebuts the economic justifications used to explain why a licensed regime is better than an unlicensed regime.

1. Scarcity may be a regulatory artifact

The impetus for spectrum reform came from service providers, equipment makers, and customers wishing to offer or take advantage of new wireless services that are currently hampered by regulatory restrictions that limit access to RF spectrum. Since 1995, billions of dollars have been paid in auctions for licenses, providing tangible evidence of industry's willingness-to-pay for spectrum and providing an empirical basis for estimating the opportunity cost for using spectrum. Estimates inferred on this basis can be substantial. For example, one industry analyst used "$10 per month per subscriber" as a ballpark estimate of the on-going cost of the spectrum used to support 2G mobile services.[66]

While the auction data demonstrates that industry is willing to pay substantial amounts for exclusive use licenses, it is unclear how much of this payment reflects artificial scarcity due either to regulatory mismanagement (*i.e.,* too much spectrum being tied up under restrictive, inflexible use licenses that prevents it from being reallocated) or to exclusive licenses (*e.g.,* the desire to protect or exploit market power). Incumbents have argued that granting them flexibility would allow spectrum to be redeployed, thereby increasing supply and lowering spectrum costs. Additionally, proponents of auctions argue that to the extent that a license may convey an opportunity to earn monopoly profits, *ex ante* competition among would-be monopolists will extract any monopoly rents in the auction proceeds. If this occurs, however, it means that the expected business plan of the winner incorporates those anticipated monopoly profits.[67] The licensee has an incentive to maximize the value of its exclusive license, which includes potentially restricting future access to the spectrum, even when such access could be shared at zero cost.[68]

Certainly, if additional spectrum is made available by allocating new spectrum to commercial uses or by spectrum reform that makes it easier to use existing spectrum more intensively (*e.g.,* increasing licensing flexibility and granting secondary use easements) and more easily transferred to higher value uses (*e.g.,* by promoting the emergence of secondary markets and by allocating additional spectrum to dedicated unlicensed), the opportunity cost for spectrum should decrease.[69]

Evidence of current spectrum use suggests that licensed spectrum is under-utilized. If one drives around with a meter measuring the level of RF transmissions in the prime spectrum below 3GHz, one finds under-used spectrum most of the time, in most locales, in most of the frequency bands.[70] While some frequencies are being used intensively in some places (*e.g.,* cell phone calls that are dropped during rush hour), there is usually lots of unused spectrum in adjacent bands. This suggests that most of the observed "scarcity" is a regulatory artifact.

Furthermore, as already noted, many of the advances in wireless technology make it possible to use spectrum much more intensively without causing destructive interference. For example, one of the justifications for retaining spectrum for over-the-air television broadcasting is to protect access to free television for households with old analog televisions. Requiring customers to upgrade their televisions to take advantage of smart-receiver, digital technology would allow much more efficient utilization of the spectrum. In Berlin, policymakers determined that it was much cheaper to simply subsidize the conversion to digital receivers than to delay the conversion to digital television.[71] As explained further below, dedicated unlicensed spectrum may enhance incentives to adopt spectrally efficient technology faster.

If spectrum is *not* scarce, then one of the significant justifications for supporting exclusive licenses disappears. If there is no scarcity, then it is unnecessary to incur the bureaucratic overhead and transaction costs associated with licenses in order to allocate the resource more efficiently.

Finally, if history is any guide, then the experience to date of "Quality of Service" pricing in the Internet suggests that it may continue to be cheaper to over-provision capacity than to implement a pricing mechanism to induce more efficient utilization at the margin.[72] During the 1990s, significant academic and industry research and development went towards developing incentive-compatible pricing mechanisms to allow more efficient utilization of Internet capacity.[73] The problem was that the traditional Internet was based on a "best efforts" packet service protocol that results in increasing packet delays during periods of congestion. For delay-sensitive services like voice telephony, this presents a problem. Although numerous technologies have been implemented to support prioritized pricing, most network operators simply opted for over-provisioning rather than incur the added overhead associated with traffic metering and transaction processing. When quality-of-service pricing has been introduced, it has been employed more as a means of supporting pricing discrimination than in order to allocate scarce resources.

2. Coordination costs may be lower with unlicensed

Although spectrum reform and adoption of new wireless technologies can significantly increase spectrum supply, demand may grow even faster. Even if there is ample spectrum for most uses in most locales, localized congestion (with respect to time or location) is likely to persist at least under some circumstances. Furthermore, the adoption of efficient spectrum sharing technologies will take time and will not be uniform. For these reasons, it is important to consider how best to allocate spectrum if it remains scarce.

The standard economist answer is to rely on markets to allocate scarce resources. Although Coase (1959) made this point almost fifty years ago, regulators have been slow to move towards increased reliance on market forces. While this may be the correct solution for most scarce resources, and even for spectrum in a many cases, it is worthwhile considering the circumstances within which "market allocation" is *not* likely to offer the best mechanism for allocating scarce spectrum.

For a market to be efficient, a number of assumptions have to apply. First, it has to be possible to define the good that is to be allocated. Second, the market prices should be efficient.[74] As Benkler (2002) has explained, these assumptions may not apply in the case of spectrum. If the goal is to rely on markets to address spectrum scarcity, then the markets need to be local. That is, scarcity will arise in specific locations at specific times. As the time scale becomes shorter (*i.e.,* as one moves toward real-time markets) and the geographic region smaller, the challenges of supporting an efficient market will become greater. Under such circumstances, it may be simpler to opt for over-provisioning coupled to an admissions control protocol rather than market-allocation to address congestion.

Furthermore, even if a market price can be determined in a timely fashion, there is no guarantee that it will be efficient. If there is either monopoly or monopsony power, prices may deviate from optimal levels. As noted before, incumbents have an incentive to protect and exploit their market power. By restricting the availability of spectrum, they may be able to inflate prices to capture artificial scarcity rents. Even more perversely, they may selectively restrict spectrum access to new technologies that are expected to pose a competitive threat to their market power, thereby influencing not only end-user prices but the direction of technical change and slowing the progress of competition.[75] The history of AM and VHF opposition to FM and UHF and its adverse impact on the development of these services, as described by Hazlett (2001), demonstrates that this is a real concern.

Prices may also deviate from efficient levels if there are externalities that are not reflected in the prices. These could be negative (*e.g.,* interference) or positive (*e.g.,* network effects) that are not appropriable by the transacting parties and hence not included in the prices. For example, in the absence of suitable underlay rights, a negative externality would arise if a technology like UWB were foreclosed from using frequencies which are priced only to reflect the value of the use rights of those services that operate within licensed bands.[76] Alternatively, a new technology or service may fail to emerge if prices do not take account of the positive externalities associated with network effects.[77] While it may be possible to reform property rights so that these externalities are internalized, it may be better to simply address these externalities via a non-market mechanism.

Even if efficient prices can be set by the market, these do not always offer the best mechanism for coordinating the allocation of resources. When Coase (1959) argued in favor of using markets for allocating spectrum licenses, he was focusing on the then-current state of the wireless world and the alternative used by the FCC to allocate licenses based on a bureaucratically-expensive administrative process that was vulnerable to influence costs. This is not the modern wireless world considered here of flexible licenses for a lot of spectrum.

In Coase (1937), his seminal paper on the theory of the firm, Coase identified circumstances when markets are not likely to offer the best mechanism for allocating scarce resources. If transaction costs are sufficiently high, it may be better to allocate resources using a non-market mechanism. Transaction costs are higher when there are search and information costs, bargaining costs, or policing and enforcement costs. If scarcity is intermittent or localized, these costs may be high relative to the value of the spectrum rights that are being exchanged. Matching spectrum buyers and sellers if the market is decentralized may be expensive. Alternatively, supporting a centralized market when the transactions need to be decentralized (because scarcity is very localized) may entail substantial transaction costs. For example, consider device with only very occasional needs to communicate with anyone, and when they do communicate, the parties are seldom the same.

The value of the spectrum being sold may be small if users' willingness-to-pay to avoid "congestion" is low. For example, if the communications are inherently low value or easily shifted in time, modulation, or frequency (so as to avoid interfering) than the "prices" may be so low that coordination might be better achieved using a non-price coordination device that relies solely on signaling instead of market transactions. There are lots of "rules of the road"-type mechanisms that may achieve coordination much more effectively without requiring the overhead of a payment mechanism of enforcement. If spectrum is not scarce and transaction costs are relatively high then an unlicensed model (more like a commons) may offer a superior mechanism for allocating spectrum, as even Faulhaber and Farber (2002) concede.

3. Exclusive licenses are not essential to support market allocation of spectrum

While the preceding discussion raised questions about the feasibility and efficiency of using markets for allocating spectrum, these arguments are not conclusive. There may be situations where market-based spectrum allocation may be efficient. However, the market-based allocation does not have to be via real-time pricing, and even if it is, it does not require exclusive licenses.

On the one hand, market forces could be employed in the selection of a sharing protocol or etiquette to manage the unlicensed spectrum. This could be accomplished by delegating the selection of the protocol to an independent standards development organization.

On the other hand, exclusive licenses are not necessary to implement real-time pricing. As Noam (1995, 1998) first pointed out, and Benkler (2002) re-enforces, exclusive frequency-based licensing may make it more difficult to efficiently allocate spectrum using prices. A licensing regime based on exclusive rights to use a narrow band of frequencies in a specific geographic-area may prove too rigid and cumbersome. There is no *a priori* reason to believe that the government could not administer a real-time market (acting as the Walrasian auctioneer and clearing house) as efficiently as a private band manager; or, alternatively, why such management could not be outsourced without requiring a grant of private exclusive license rights.

Finally, because the allocation of additional spectrum to dedicated unlicensed is anticipated to occur in conjunction with – not in full replacement of – increased flexibility for licensed spectrum, market trading of exclusive licensing and dedicated unlicensed could co-exist in different frequency bands below 3GHz. Indeed, the availability of low cost unlicensed spectrum would provide a check on the ability of exclusive licensees to extract artificial scarcity rents and would provide a haven for those users and technologies for which market allocation of spectrum may not be efficient, as noted above.

4. Exclusive licenses not necessary to promote investment incentives

Exclusive licenses are also justified to promote investment incentives. On the one hand, exclusive licenses can provide incentives to use spectrum more efficiently. On the other hand, exclusive licenses are argued to be necessary to promote investment in carrier infrastructure. While these benefits may be true about exclusive licenses, they are neither the only nor best way to promote efficient spectrum use and investment. Although related, these two rationales involve distinct notions and are addressed in the following sub-sections.

a) Incentives to use spectrum efficiently

A common criticism of the unlicensed model is that it lacks incentives to use spectrum efficiently, resulting in a "Tragedy of the Commons." This arises when each user fails to take into account the negative impact of their usage on the experience of others, resulting in "congestion" or harmful interference.

By assigning a private property right to the spectrum, the owner becomes the residual claimant to the spectrum, and thereby has an enhanced incentive to manage the spectrum efficiently. Of course, this assumes that the benefits of using the spectrum are fully appropriable, which is unlikely to be the case for several reasons. First, because spectrum licenses are not granted in perpetuity and are constrained in other ways that limit the owner's ability to fully exploit the benefits of ownership. Second, efficient management assumes that the market allocation is efficient and I have already explained why that might not be so. Third, it ignores that a commons could be owned collectively and adopt a collective management scheme that could be equally efficient. There is no *a priori* reason to presume that resource ownership in common with common management is less efficient than private ownership with private management.[78]

Additionally, as Benkler (2002) points out, incentives to invest in spectrum-efficient technology may be improved in a unlicensed world. If users know that they may have to contend with congestion, this can enhance their incentives to invest in technologies that are robust to interference. While it is possible that these technologies could either ameliorate interference (*e.g.,* switch to an unused channel when interference is detected) or make matters worse (*e.g.,* boost power to drown out the competing signal), additional "rules of the road" could be designed to constrain the types of interference responses adopted to those that are collectively efficient.[79]

b) Incentives to invest in wireless infrastructure

Some proponents of exclusive licenses argue that these are needed to provide carriers and customers incentives to invest in radio equipment and services because such long-lived assets are co-specialized with the frequencies that they use.

Because constructing a traditional carrier network requires large investments that may be substantially sunk, a carrier's incentive to invest is reduced by the threat of interference. By granting some protection against future interference over the investment horizon,[80] an exclusive license lowers the *ex ante* costs of investing in infrastructure, and thereby may promote investment.[81]

While this reason has provided a valid rationale for why service providers have claimed they need exclusive licenses, and also why these licenses ought to be for long terms and subject to easy renewal, the service provider model is not the only business model for offering wide-area communication services. For example, consider the case already cited of the device that only wants to communicate occasionally, and which may also be quite inexpensive. In such case there, there is no large network investment that needs to be protected. While such services *may* be provided over a service provider's network, this does not have to be the case.

Moreover, advances in wireless technology are rendering this traditional rationale less relevant. First, wireless technology is increasing the frequency-agility of radio systems. Even without the ideal of "cognitive radios," software radio and modern system engineering techniques are making network equipment more modular and more upgradable. The behavior of radios can be changed in many ways via remote software upgrades or partial upgrades (board replacements) that do not require replacement of the entire radio. Second, much of the investment in a carrier's network that is long-lived (towers, cell sites) remains useful even if all of the electronics need to be replaced; and the electronics have much shorter useful lives (so do not justify granting a license in perpetuity to protect against hold-up costs). Third, with the development of secondary spectrum markets and flexible licensing, exit costs are reduced which further reduces the need for protection from exclusive licenses. Taken together, these advances and changes in the market make the spectrum used and the infrastructure that use it *less* co-specialized, thereby reducing the traditional basis underlying the need for exclusive licenses to protect carrier investment incentives.

Furthermore, to the extent incumbents fear competition from new technologies, they may seek to foreclose these technologies by denying them access to spectrum.[82] While efficient secondary markets for spectrum would reduce the risk of such foreclosure, it would not eliminate this risk.

5. Exclusive licenses not necessary to manage interference

Real spectrum "scarcity" arises when two uses of the same spectrum interfere with each other. One way this can be managed is by assigning a property right that allows one user to exclude the other. This property right can provide the basis of a market allocation of spectrum. However, I have already explained why such a market mechanism may not always be the most efficient way to allocate scarce spectrum, and why exclusive licenses are not necessary and may be inferior to dedicated unlicensed even if a market allocation process is used.

It is also sometimes argued (Hazlett, 1998) that the owner of an exclusive license would be more likely to adopt the efficient sharing protocol than would a government manager of dedicated unlicensed spectrum. There are several responses to this argument. First, dedicated unlicensed that relies on a sharing protocol need not rely on an administrative government process to select the protocol, as already explained. Second, a dedicated unlicensed regime involves more than just an algorithm for allocating scarce spectrum. While the sharing protocol is important, it is not the only feature that distinguishes unlicensed from licensed.

Third, while an efficient market ought to induce adoption of an efficient sharing protocol, there are a number of reasons which have already been cited for why a market based on exclusive licenses may fail to be efficient. Allocating additional spectrum for dedicated unlicensed *and* for exclusive licenses will provide an interesting test of which model adopts the most efficient mechanisms for sharing. An analogous problem is associated with the economics of industry standardization: sometimes *de facto* standardization offers the best solution, whereas other times, the full process of a standards development organization is needed to protect against capture by a limited set of interests.

Finally, it is sometimes argued that exclusive licenses are needed to enable more efficient enforcement of whatever interference management regime is adopted. The claim is that by moving to a regime based on property rights, enforcement via the Courts will replace enforcement via a technical protocol or via an administrative body like the FCC and that Courts are inherently more efficient (Hazlett, 2001). The justification for this last claim relies, in part, on the vulnerability of government administration to influence costs. However, as Benkler (2002), points out, tort enforcement by the Courts is not necessarily better than enforcement by a different branch of government. Both are vulnerable to influence costs and both may result in lengthy delays and inefficient outcomes. Property rights for spectrum are inherently ambiguous, and should underlay and overlay easements be adopted, will become even more so.

Furthermore, as already explained, dedicated unlicensed could be enforced via a market mechanism (*e.g,* an industry standards body). Even voluntary certification of compliance with the "industry specified congestion management protocol" could be effective. While there may still be opportunistic defections, no enforcement mechanism is perfect and the benefits of better enforcement must be weighed against its costs. If spectrum is relatively plentiful (and hence low cost), voluntary compliance may be sustainable as an individually rational equilibrium.

Finally, advances in technology such as cognitive radios will make it easier to decentralize interference management.

B. Dedicated unlicensed below 3GHz preserves regulatory diversity

Allocating additional spectrum for dedicated unlicensed in the lower frequency bands helps retain regulatory flexibility and diversity. Preserving such diversity only in higher frequencies fails to recognize the important fact that different frequencies are not perfect substitutes.

The regulatory diversity is valuable because no enforcement mechanism is perfect and the uncertainty regarding the optimal regulatory approach is greatest in times of rapid technical progress and industry transformation. Wireless services are helping to drive industry convergence that is blurring the boundary between computing and communications, content and conduit, broadcasting and telecommunications, and wired and wireless networks.

Providing for the co-existence of multiple regulatory models supports multiple experiments and provides an element of "future proofing." With respect to the evolution of broadband wireless services, we have already seen such benefits delivered by the surprise success of WiFi services deployed in the ISM unlicensed band. Although this spectrum is crowded and was not generally regarded as prime spectrum, it has given root to a technology that has forced a rethinking of the whole way in which broadband wireless services are delivered.

Finally, achieving spectrum reform will be difficult. Providing additional spectrum for dedicated unlicensed services in the lower-frequency spectrum may enhance the likelihood that the necessary reform will be accomplished in a timely fashion. I have already identified a number of ways in which allocating dedicated unlicensed spectrum might help to ameliorate opposition to spectrum reform.

C. Dedicated unlicensed supports innovation and investment

In addition to encouraging investment in smart radio technology, dedicated unlicensed is also more compatible with decentralized, distributed models for industry evolution. While the service provider model is likely to remain an important feature in the landscape for wireless services, especially wide area communication services, it is not the only model that should be allowed to exist.

The critical feature of dedicated unlicensed is that *no* private interest has a right to deny access to potential users. Because users do not have to negotiate a service agreement before accessing unlicensed spectrum, and because there is no one that has an exclusive right to exclude them from using the spectrum, unlicensed spectrum lowers the costs for decentralized, small-scale entry and viral industry growth. This can foster distributed experimentation. Devices in isolated areas that are not intended to be part of large integrated networks may find use of such spectrum especially attractive. However, as the WiFi example demonstrates, technologies originally developed for one type of market may evolve to serve other needs.

Although the distributed networks may remain independent, they may also be interconnected. This could be via the public telecommunications network comprised of interconnected service provider networks. When part of the larger communications infrastructure, these distributed, decentralized wireless networks can support edge-based innovation. Innovations can be adopted incrementally, without requiring changes to core network components or without directly confronting the network effects that can make legacy applications so difficult to replace. While network effects contribute to the value of being part of a larger network, they can sometimes pose a barrier to innovation.

Even if unlicensed proves most useful as a test-bed for new technologies which elect to migrate to licensed spectrum if they prove successful and congestion management becomes more of an issue, this would provide a sufficient basis for supporting the unlicensed model. Moreover, there are likely to be technologies that we have not yet imagined that may find unlicensed offers a better operating environment. The growth of wireless grids or ad hoc networks may be better supported in unlicensed spectrum.

Finally, unlicensed spectrum may be more likely to support the emergence of networks that are based on an equipment-provider model. That is, networks that may be created when end-user's deploy equipment that can operate both as end-nodes and as relay or transmission nodes. By linking series of such devices together in a "grid" or "mesh," it is possible to create a network capable of supporting communications over a wide area without the intercession of a service provider. Although a service-provider may be involved, and interconnection with a service provider at some level is likely, such "ad hoc" networks offer an alternative strategy for building up communications infrastructure. If successful, these could offer additional sources of competition for incumbents, further contributing to consumer choice. In response to the threat of such competition or in recognition of the benefits offered by new technologies, service providers may be induced to integrate these new services to enhance their service offerings. Indeed, as with WiFi/3G, unlicensed model can (1) complement traditional service provider business models (cellular); (2) assist in wireline/wireless convergence (e.g., WiFi supported via DSL); or provide a platform for alternative entry platforms (e.g., wireless local loop).

VI. Conclusions and Policy Recommendations

There is general agreement among industry analysts that the traditional models of spectrum management are in need of reform. Most economists agree that the reform should seek to increase the ability of market forces to shape how spectrum is allocated and used. Traditional licenses that were encumbered with restrictions on the choice of technology, the services offered, their coverage, and the transferability of access rights have imposed a high opportunity cost for spectrum for many advanced communication services, while precluding the deployment of under-utilized spectrum to higher-value uses. This has increased industry costs, reduced incentives to innovate, and slowed the deployment and adoption of new services.

One solution that has been proposed is to transition to regime of tradable property rights for spectrum based on exclusive use frequency licenses. An alternative approach for managing spectrum would be to allocate a band or bands of frequencies for unlicensed uses. There seems to be an emerging consensus among those who support increased reliance on market forces that exclusive use licenses offer a superior mechanism for spectrum management, especially for the valuable lower frequency spectrum below 3GHz. The spectrum in these bands that is available for commercial use (and much of it is not and remains under government control) is heavily populated by licensed incumbents. Support for using exclusive licenses for lower frequency spectrum is justified, in part, via recourse to Coase's (1959) argument that markets do a better of job of allocating scarce resources than do central governments. Moreover, it is argued support for unlicensed uses can be adequately provided via underlay and overlay easements to allow secondary usage of licensed spectrum.

While the transition to a flexible licensing regime and making provision for unlicensed easements are important reform policies, there is also a need to allocate additional spectrum for dedicated unlicensed use in the lower frequencies below 3GHz. An allocation on the order of another 100 to 300MHz would leave plenty of spectrum for the exclusive licensing. Making such a provision is desirable because unlicensed use supports a fundamentally different model for how wireless services may be developed and deployed. This offers a valuable contribution to the wireless ecosystem, as the success of WiFi in recent years attests.

Opposition to dedicated unlicensed is often conflated with the view that unlicensed is inconsistent with auctions, implies spectrum use should be "free," or that supporting unlicensed means opposing liberalization of licensed spectrum. These are misconceptions. An allocation of additional unlicensed spectrum could be included as part of a spectrum auction. Unlicensed use is not "free" but it does preclude a private party using its license to extract rents for access to the spectrum. And, unlicensed spectrum does not imply more regulation and is consistent with increased reliance on market forces.

Additional spectrum for dedicated unlicensed use is important because secondary use easements are neither a foregone conclusion nor an adequate substitute. Furthermore, an allowance below 3GHz is important because spectrum at different frequencies is useful for different things. Additional spectrum for dedicated unlicensed use above 3GHz will be available, and in any case, the difference between a licensing and unlicensed regime are less pronounced at higher frequencies.

Promoting regulatory diversity is consistent with supporting increased reliance on market forces since no regime will be completely free of regulation and its incumbent distortions. By providing for multiple models in the lower frequencies, the forces of market-fueled innovation and competition are enhanced.

Bibliographic References[83]

Bazelon, Coleman (2002), "Use Administrative Law Judges to Adjudicate Interference Disputes Between Licensees," Comments Submitted In the Matter of Issues Related to the Commission's Spectrum Policies, Federal Communications Commission, ET Docket 02-135, July 8, 2002.

Benkler, Yochai (2002), "Some Economics of Wireless Communications," 16 *Harvard Journal of Law and Technology* 25 (2002).

Benkler, Yochai (1997), "Overcoming Agoraphobia: Building the Commons of the Digitally Networked Environment," *Harvard Journal of Law and Technology*, 11 (Winter 1997-98).

Blumenthal, Marjorie and David Clark (2001), "Rethinking the design of the Internet: The end-to-end arguments vs. The brave new world," ACM Transactions on Internet Technology, Aug. 2001.

Carter, Kenneth, Ahmed Lahjouji, and Neal McNeil (2003), "Unlicensed and Unshackled: A Joint OSP-OET White Paper on Unlicensed Devices and Their Regulatory Issues," OSP Working Paper Series #39, Federal Communications Commission, May 2003.

Cave, Martin (2002), "Review of Radio Spectrum Management," Independent Review Report prepared for Department of Trade and Industry, United Kingdom, March 2002 (available from: http://www.ofcom.org.uk/static/archive/ra/spectrum-review/index.htm).

Coase, Ronald (1959), "The federal communications commission," *Journal of Law & Economics*, 2 (1959) pages 1–40.

Coase, Ronald (1937), "The nature of the firm," in *Readings in Price Theory*, Stigler and Boulding (ed), R.D. Irwin: Chicago, 1952 (essay originally published in 1937).

Comments of 37 Concerned Economists (2001), In the Matter of Promoting Efficient use of Spectrum through Elimination of Barriers to the Development of Secondary Markets, Before the Federal Communications Commission, WT Docket No. 00-230, February 7, 2001.

Cramton, Peter (2002), "Spectrum Auctions," in *Handbook of Telecommunications Economics*, Martin Cave, Sumit Majumdar, and Ingo Vogelsang, eds., Amsterdam: Elsevier Science B.V., Chapter 14, 605-639, 2002.

European Commission, "Green Paper on Radio Spectrum Policy," Commission of the European Communities, Brussels, COM(1998)596, December 9, 1998 (available from: http://europa.eu.int/ISPO/spectrumgp/sgptxt/sgp.pdf) (hereafter, "EC Green Paper on Spectrum Policy (1998)").

Faulhaber, Gerald R., and David Farber (2002), "Spectrum Management: Property Rights, Markets, and the Commons," AEI-Brookings Joint Center, Working Paper 02-12 (December 2002).

FCC (2003a), *Notice of Inquiry and Notice of Proposed Rule-making*, In the Matter of Establishment of an Interference Temperature Metric to Quantify and Manage Interference and to Expand Available Unlicensed Operation in Certain Fixed, Mobile and Satellite Frequency Bands, Federal Communications Commission, ET Docket No. 03-237, November 13, 2003 (hereafter, *FCC Interference NPRM (2003)*).

FCC (2003b), *Report and Order*, In the Matter of Allocations and Service Rules for the 71-76 GHz, 81-86 GHz and 92-95 GHz Bands, Federal Communications Commission, WT Docket No. 02-146, October 16, 2003 (hereafter, *FCC WT 02-146 Millimeter Band Proceeding*).

FCC (2003c), *Memorandum Opinion and Order and Further Notice of Proposed Rulemaking*, In the Matter of Revision of Part 15 of the Commission's Rules Regarding Ultra-Wideband Transmission Systems, ET 98-153 (FCC 03-33), February 12, 2003.

FCC (2000), *Notice of Proposed Rulemaking (NPRM)*, In the Matter of Promoting Efficient Use of Spectrum Through Elimination of Barriers to the Development of Secondary Markets, Federal Communications Commission, Docket WT 00-230, November 9, 2000.

Gaynor, Mark, Lee McKnight, Junseok Hwang, and Jim Freedman (2003), "Wireless Grid Networks and Virtual Markets," paper presented to International Conference on Computer, Communication and Control Technologies, Orlando, Florida, July 31-August 2, 2003 (available at: http://wirelessgrids.net/docs/CCCT03_Gaynor_T244WL.pdf).

Gilder, George (1993), "The New Rules of Wireless," *Forbes ASA*P, March 29, 1993.

Grossglauer, Matthias and David Tse (2002), "Mobility Increases the Capacity of Ad Hoc Wireless Networks," *IEEE/ACM Transactions on Networking*, Vol. 10, No. 4 (August 2002) 477-486.

Hazlett, Thomas (2001) "The Wireless Craze, The Unlimited Bandwidth Myth, The Spectrum Auction Faux Pas, and the Punchline to Ronald Coase's "Big Joke": An Essay on Airwave Allocation Policy" *Harvard Journal of Law and Technology* (Spring 2001).

Hazlett, Thomas (1998) "Spectrum Flash Dance: Eli Noam's Propoal for 'Open Access' to Radio Waves," *Journal of Law and Economics* 41 (no. 2, pt. 2, October): 805-820.

Ikeda, Nobuo and Lixin Ye (2003), "Spectrum Buyouts: A Mechanism to Open Spectrum," Draft paper, October 17, 2003.

Isenberg, David, "Rise of the Stupid Network," *Computer Telephony*, August 1997, pages 16-26.

Jeacock, Terry (2004), "Spectrum Management Activities of the ITU," presentation to Workshop on Radio Spectrum Management for a Converging World, International Telecommunications Union (ITU), February 2004 (available at: http://www.itu.int/osg/spu/ni/spectrum/index.html).

Johnston, James and J. H. Snider (2003), "Breaking the Chains: Unlicensed Spectrum as a Last-mile Broadband Solution," Spectrum Series Working Paper #7, New America Foundation, Washington, DC, June 2003 (available at http://www.newamerica.net)

Judge, Peter, "Wi-Fi to overtake broadband," TECHWORLD, July 22, 2003 (available at: http://www.techworld.com/news/index.cfm?fuseaction=displaynews&NewsID=293)

Katz, Michael and Carl Shapiro (1986), "Technology Adoption in the Presence of Network Externalities," *Journal of Political Economy*, vol. 94, (1986) pages 822-841.

Kolodzy, Paul (2002), *Spectrum Policy Task Force*, Office of Engineering & Technology, Federal Communications Commission, November 2002.

Konston, K. (2002), "In Pursuit of a Wireless Bill of Rights," presentation to the Spectrum Management Working Group, September 18, 2002.

Kwerel, Evan and John Williams (2002), "A Proposal for a Rapid Transition to Market Allocation of Spectrum," OPP Working Paper #38, Federal Communications Commission, November 2002.

Landler, Mark (2003), "Germany zaps into digital television," *International Herald Tribune Online*, November 4, 2003 (available at: http://www.iht.com/cgi-bin/generic.cgi?template=articleprint.tmplh&ArticleId=116186).

Lehr, William and Lee McKnight (2003), "Wireless Internet Access: 3G vs. WiFi?," *Telecommunications Policy*, 27 (2003) 351-370.

Lehr, William, Sharon Gillett, and Fuencisla Merino (2003), "Software Radio: Implications for Wireless Services, Industry Structure, and Public Policy," *Communications and Strategies*, IDATE, Issue 49 (1st Quarter 2003) 15-42.

Lessig, Lawrence (2001), The Future of Ideas: The Fate of the Commons in a Connected World, New York: Random House, 2001.

Loeb, Martin and Wesley A. Magat (1979), "A Decentralized Method of Utility Regulation," Journal of Law and Economics, October 1979, pp. 399-404.

McHenry, Mark (2001), "Solving the West Virginia Broadband Access Problem Using Automated Secondary Spectrum Technology," presentation to Russell J. Lefevre, Office of Senator John D. Rockefeller IV, Shared Spectrum Company, Vienna, VA, July 16, 2001.

McKnight, Lee, William Lehr, and James Howison (2003), "Coordinating User and Device Behavior in Wireless Grids," paper prepared for Virtual Markets and Wireless Grids (NSF grant #0227879), Syracuse University, October 2003.

McKnight, Lee and Joe Bailey (1998), *Internet Economics*, MIT Press: Cambridge, MA, 1998.

McMillan, John (1994) "Selling Spectrum Rights." *Journal of Economic Perspectives* 8 (no. 3, summer): 145-162.

Melody, William (2001), "Spectrum Auctions and Efficient Resource Allocation: Learning from the 3G Experience in Europe," TelecomReform, Volume 1, Number 1 (April 2001) (available from: http://www.telecomreform.net/PDF_files/Policy_Forum_tr-1.pdf).

Noam, Eli (2001), "The Next Frontier for Openness: Wireless Communications," draft paper presented at 2001 Telecommunications Policy Research Conference, Alexandria, VA, October 2001.

Noam, Eli (1998), "Spectrum Auction: Yesterday's Heresy, Today's Orthodoxy, Tomorrow's Anachronism. Taking the Next Step to Open Spectrum Access," *Journal of Law and Economics* 41(1998) pages 778-80.

Noam, Eli (1995), "Taking the Next Step Towards Open Spectrum Access," *IEEE Communications Magazine,* 33 (1995) 66.

Odlyzko, Andrew (1998), "The economics of the Internet: Utility, utilization, pricing and Quality of Service", mimeo, AT&T Labs, July 7, 1998 (available at: http://www.dtc.umn.edu/~odlyzko/doc/internet.economics.pdf).

Ostrom, Elinor (1990), *Governing the Commons: The Evolution of Institutions for Collective Action*, New York: Cambridge University Press.

Owen, Bruce and Gregory Rosston, "Spectrum Allocation and the Internet," in *Cyber Policy and Economics in an Internet Age*, William Lehr and Lorenzo Pupillo (ed), Kluwer Academic Press: Norwell, MA, November 2002.

Peha, Jon (2003), "Relieving Spectrum Scarcity Through Real-time Secondary Markets," Presentation Slides, ISART 2003 Conference, Boulder Colorado, March 2003.

Peha, Jon and Durga Satapathy (2000), "A Novel Co-existence Algorithm for Unlicensed Fixed Power Devices," paper presented to *IEEE Wireless Communications and Networking Conference (WCNC)*, September 2000.

Reed, David (2003), "Constructing a Communications Ether that Can Grow and Adapt," Presentation Slides, April 16, 2003.

Reply Comments of the New America Foundation et al. (2003), In the Matter of Additional Spectrum for Unlicensed Devices Below 900MHz and in the 3GHz Band, Before the Federal Communications Commission, ET Docket No. 02-380, May 16, 2003.

"Report Examines Hotspot Growth and Profitability," Broadband Wireless OnLine, June 30, 2003 (available at: http://www.shorecliffcommunications.com/magazine/news.asp?news=2081)

Rothkopf, Michael and Coleman Bazelon (2003), "Interlicense Competition: Spectrum Deregulation without Confiscation or Giveaways," Spectrum Series Working Paper #8, New America Foundation, August 2003.

Shim, Richard (2004), "Report: Wi-Fi gear moving on the double," CNET News.com, January 14, 2004 (available at: http://news.com.com/2100-7351-5141002.html).

Spectrum Policy Task Force (2002a), *Report of the Unlicensed Devices and Experimental Licenses Working Group*, Federal Communications Commission, November 15, 2002.

Spectrum Policy Task Force (2002b), *Report of the Spectrum Efficiency Working Group*, Federal Communications Commission, November 15, 2002.

Ting, Carol, Johannes Bauer, and Steven Wildman, "The U.S. Experience with Non-traditional approaches to spectrum management: Tragedies of the commons and other myths reconsidered," paper presented to 31st Research Conference on Communication, Information and Internet Policy, Arlington, VA, September 19-21, 2003

Wanichkorn, Kanchana and Marvin Sirbu, "The Role of Fixed Wireless Access Networks in the Deployment of Broadband Services and Competition in Local Telecommunications Markets," paper presented to Telecommunications Policy Research Conference, Alexandria, VA, 2002.

Werbach, Kevin (2003), "Radio Revolution: The Coming Age of Unlicensed Wireless," white paper prepared for New America Foundation, Washington, DC, December 2003.

Endnotes

[1] This research was conducted with support from the MIT Research Program on Internet and Telecoms Convergence (http://itc.mit.edu), as well as the Communications Futures Program (http://cfp.mit.edu).

[2] See, for example, *Comments of 37 Concerned Economists* (2001), Hazlett (2001), Kwerel & Williams (2002), or Fahlhaber & Farber (2002) for the majority view among economists on the need for flexible licensing. See Noam (1995) for an early contrary minority view.

[3] See Kolodzy (2002).

[4] See Benkler (2002), Werbach (2003), Gilder (2003), or Lessig (2001).

[5] The choice of 3GHz as a cut-off is somewhat arbitrary. It was chosen to include the MMDS spectrum at 2.5GHz as well as the ISM Unlicensed spectrum at 2.4GHz and to approximate the upper bound for non-line-of-sight transmission. The benefits of lower-frequency spectrum are even greater at still lower frequencies, say below 1GHz which is dominated by broadcast television. I am using "lower" instead of "low" frequency in this paper to refer to frequencies below 3GHz to avoid confusing radio engineers who refer to lower-frequency spectrum as anything below 300Khz. (Thanks to Timothy Shepard for pointing this out.)

[6] A significant share of spectrum is reserved for government use and is managed by the National Telecommunications Information Agency (NTIA). The spectrum that is allocated for commercial and public use is managed by the Federal Communications Commission. The focus of this paper is on management models for commercial and public use spectrum, however, the author supports reallocating additional spectrum from government use to the private sector. Such a reallocation would benefit both providers and users of commercial services, and displaced government users who will benefit from the innovations in wireless services that would be promoted.

[7] Over time, the FCC has liberalized licensing rules for different bands and services such that the rules that apply differ by frequency. Historically, the FCC has been pretty liberal in allowing commercial licenses to be transferred for existing uses (*e.g.,* allowing licensees to trade territories or to accommodate corporate restructuring).

[8] See for example Kolodzy (2002) which presents the report of the FCC's Spectrum Policy Task Force. Similar discussions have been occurring around the globe. For example, in the UK (Cave, 2002), in the European Community (EC Green Paper on Spectrum Policy, 1998), in the ITU (Jeacock, 2004), and elsewhere around the world (see http://www.itu.int/osg/spu/ni/spectrum/index.html for briefing presentations from around the world from a workshop at the ITU in February 2004).

[9] See FCC (2000).

[10] The super-heterodyne transceiver circuit, which has provided the basic architecture for radio design, was invented by Edwin Armstrong in 1917.

[11] Exclusive-use licensees share the spectrum among multiple users (*e.g.,* mobile operator supporting numerous simultaneous calls or an over-the-air broadcaster providing service to many homes in the broadcast market). The "exclusivity" arises because of the licensees right to determine who is allowed to share the spectrum.

[12] For example, the interference threshold associated with broadcast television licenses is set to accommodate the needs of those receivers that are furthest from the broadcasting station's tower (where the

signal is weakest) but which are still expected to be able to be view the station. Receivers closer to the transmission tower or with "smarter" signal processing capabilities could tolerate higher levels of "interference."

[13] See Lehr, Gillett, and Merino (2003) for further discussion of the implications of software radios.

[14] See Spectrum Policy Task Force (2002a) and Werbach (2003) for user-friendly discussions of some of the relevant developments.

[15] For example, David Reed (2003) argues that spectrum capacity may increase as users are added to the system. Also, see Grossglauer and Tse (2002).

[16] See Carter, Lahjouji, and McNeil (2003) for a survey of unlicensed uses and regulatory issues. While unlicensed use of wireless spectrum in the 900MHz and 2.4GHz bands has thrived, unlicensed devices have had much more limited success in certain other bands (*e.g.,* see Ting, Bauer, and Wildman, 2003, regarding use of the Citizen Radio and Unlicensed PCS bands).

[17] WiFi, or 802.11b, is the wireless Ethernet LAN standard. See Lehr & McKnight (2003) for further discussion of WiFi.

[18] These estimates are from an In-Stat/MDR Report (see, Shim, Richard (2004), "Report: Wi-Fi gear moving on the double," CNET News.com, January 14, 2004, available at: http://news.com.com/2100-7351-5141002.html).

[19] There are a continuously evolving class of related standards that support "WiFi"-like communications over longer distances, at higher bandwidths, in different frequency bands, and with support for additional applications (*e.g.,* added security and network management functionality, support for real-time services, etc.). See http://grouper.ieee.org/groups/802/11/main.html for information on these standards or Lehr & McKnight (2003), which provide additional references.

[20] See "Report Examines Hotspot Growth and Profitability," Broadband Wireless OnLine, June 30, 2003 (available at: http://www.shorecliffcommunications.com/magazine/news.asp?news=2081)

[21] See Judge, Peter, "Wi-Fi to overtake broadband," TECHWORLD, July 22, 2003 (available at: http://www.techworld.com/news/index.cfm?fuseaction=displaynews&NewsID=293).

[22] WiFi networks may be open or closed. Many users do not activate the security features of WiFi and leave their networks open either intentionally or through benign neglect. When the network is open, anyone with a WiFi-enabled communication device which is within range of the base station can access the network. In addition, some publicly-spirited individuals, community groups, government organizations, and firms sponsor free-access WiFi hotspots. For example, see http://www.lights.com/freenet/ for a directory of "freenets" around the world.

[23] That is, WiFi can be integrated into a 3G network to provide high-speed hot spot access that increases the value of the lower-bandwidth but longer-range 3G services. Alternatively, WiFi can provide a substitute service for 3G. With the addition of Voice-over-IP and further improvements in WiFi technology, the potential competition between 3G and WiFi could intensify. See Lehr & McKnight (2003) for further discussion.

[24] For a perspective on the role of UWB in home networking see Ultra Wideband FAQs at http://e-www.motorola.com/webapp/sps/site/overview.jsp?nodeId=02XPgQhHPR02204720. See FCC (2003c) for

recent FCC decision permitting low-power UWB use and see http://www.uwb.org for information and links regarding the activities of the UWB working group.

[25] The need to accommodate legacy technology increases as the pace of adoption of new technologies increases, allowing multiple generations of technology to co-exist. Technologies like software radio can accelerate adoption by lowering the costs of updating systems (*e.g.,* remote software upgrades replace hardware replacement for base stations) and by reducing the costs of managing heterogeneity (*i.e.,* devices can support multiple radios to facilitate interoperability).

[26] Wireless grids or *ad hoc* networks provide an extreme version of such networks. In a wireless grid, each end-user node is also a repeater. By cooperatively sharing their capacity, such networks could support end-to-end services without the coordination of a centralized planner. See Lippman and Reed (2003); McKnight, Lehr, and Howison (2003); or Gaynor, McKnight, Hwang, and Freedman (2003) for further discussion of the implications of these new networking trends.

[27] For example, see Isenberg (1997) or Blumenthal and Clark (2003).

[28] It is worth noting that while the Task Force recommends primarily relying in the licensing model, it does not argue that this should be the only model in the lower frequencies (which they refer to as frequencies below 5GHz, see Kolodzy, 2002). The Task Force advocacy of co-existence between licensed and unlicensed below 5GHz is consistent with the arguments made here.

[29] The relationship between frequency and propagation is complex and transmissions in each band offer advantages and disadvantages. As frequency increases, wavelength decreases, which impacts the way the RF waves interact with obstacles along the transmission path (air molecules, rain drops, trees, doorways, hills, etc.).

[30] This is due in part to market scale and learning effects. As the market for and experience with operating at higher frequencies grows, the cost disparity in the associated electronics will decrease. One important effect is that higher frequency antennas can be smaller.

[31] That is, the RF spectrum extends from 3Khz to 300GHz. There is only 3GHz of lower-frequency spectrum as defined here, as opposed to almost a 100GHz above (of currently usable spectrum). Thus, if one is simply counting MHz, there is obviously more potentially usable frequency above 3GHz than below 3GHz. However, this comparison is somewhat misleading because, as is explained here, different spectrum has different propagation properties and so a 100MHz at 700MHz may allow you to do more or less than at 10GHz, depending on what you want to do. Moreover, the 3GHz upper threshold is somewhat arbitrary but is intended to include the unlicensed spectrum currently used by WiFi (2.4GHz) and the MMDS (2.6GHz) spectrum that is under review for reform. While the WiFi technology was originally developed as a WLAN service at ranges of a few hundred feet, its range can be extended to several miles with directional antennas and certain other modifications. Additionally, MMDS systems were originally developed to provide a wireless local access platform for service providers over MAN distances and improvements in MMDS have increased the ability of technologies in this class to provide NLOS service. In contrast, the challenges appear much great associated with supporting NLOS or long-range communications using frequencies above 3GHz (*e.g.,* in the 5GHz unlicensed spectrum where 802.11a WLANs operate).

[32] This includes broadcast entertainment (radio and television), mobile telephone services, and narrow-band control services.

[33] That is, when it was difficult/expensive to digitize higher-frequency (high-sampling rate) signals, services were deployed using lower-frequency channels.

[34] The savings are based on comparing the cost of operating a broadband wireless local access system using OFDM modulation and indoor CPE (desk-top antennas) at 700 MHz instead of 2.6GHz (see Wanichkorn and Sirbu, 2002, page 25). Analogous effects were confirmed by Chris Knudsen, Vulcan Partners, in private correspondence, and by Mark McHenry, Shared Spectrum Company (see McHenry, 2001).

[35] Installation becomes feasible in expanded set of locations (*e.g.,* where LOS is not available such as inside the home) and does not require costly antenna placement (*i.e.,* customer self-install can replace service-provider on-site installation).

[36] The physics of RF transmission do not imply that it takes more power to transmit a bit of information at a higher frequency. If the aperture of the receiving antenna is kept constant, then the power required to transmit does not depend on the frequency. Since the size of the antenna can shrink as the frequency increases, it is possible to design fancier antennas using the same form factor for a lower frequency antenna. What this means is that with more advanced technology, it should be possible to allow higher frequency operation for small hand-held devices without requiring more power per bit transmitted. But, this is likely to incur higher antenna costs, at least in the near term. However, if the data rate goes up, which is often one of the advantages of operating at a higher frequency, then more power will be used but this is a function of the data rate supported rather than the frequency at which it is supported.

[37] This is the approach that has been adopted by the FCC for spectrum in the millimeter bands above 70GHz (see *FCC WT 02-146 Millimeter Band Proceeding*).

[38] Beam forming antennas can facilitate much more efficient use of spectrum in all frequency bands (spatial reuse).

[39] That is, the exclusive license does not allow arbitrary exclusion of uses that would not otherwise be interfering but does provide recourse to protect the licensees service from an interfering use. Analogously, the certification rules included in Part 15 are intended in part to ensure that the power limit restrictions that are intended to limit interference conflicts in unlicensed spectrum are respected.

[40] Cite: 37 Economists, Kwerel & Williams, Farber & Fahlhaber, etc.

[41] However, because such reforms remain contentious, there are "transition" benefits to allocating additional dedicated unlicensed spectrum now. While it is hoped that liberalization of licenses will progress rapidly, the final outcome is far from assured. A commitment to additional unlicensed at this stage could ensure that additional spectrum for this model of development is guaranteed and would help clarify the debate for how licenses ought to be liberalized. This would contribute to reducing regulatory uncertainty and would likely reduce the contentiousness of the debate over licensed spectrum. (That is, by muting arguments that unlicensed and licensed spectrum are in contention.)

[42] The dedicated spectrum could be provided by releasing additional government spectrum for commercial use.

[43] This paper does not attempt to make a specific proposal as to which frequencies or how much frequency below 3GHz ought to be allocated for dedicated unlicensed use, or even whether it is better to allocate the frequency in a contiguous block or in multiple blocks with different management schemes. Each specific proposal would need to be evaluated with respect to how the transition would be managed (how to address the needs of incumbents and other stakeholders?) and what institutional framework should be used to support congestion management in the unlicensed framework (protocol or market? Who decides?). The 100-300MHz estimate is used to suggest the magnitude of the allocation that ought to be considered (*i.e.,* to exclude trivial allocations), that are achievable (*i.e.,* there is substantially more than 300MHz of spectrum

that is currently under-utilized below 3GHz, much of it currently restricted to government use), and that would provide enough bandwidth to allow for innovative services and substantial growth in users. Current and near future modulation techniques can code one to a few bits per hertz. While these may be increased, there are theoretical limits to the information carrying capacity of frequency that must be respected. Allocating between 100 to 300MHz would allow peak data rates in the 100Mbps to 1Gpbs range, thereby ensuring that the wireless services were not artificially constrained to slower speeds because of regulatory limits.

[44] See, for example, Bazelon (2002).

[45] This is analogous to the problem of management compensation and the correct balance between salary, bonuses, and equity (ownership) participation in the firm. Ownership may help but is not necessary nor sufficient to induce managers to make decisions which are optimal for investors.

[46] There are several proposals for how these might be implemented, including adopting a "bill of rights" for unlicensed wireless devices (see Konston, 2002). Alternatively, a technical protocol could be used that would address interference management issues (see Peha, 2000 for an example of a technical solution for sharing).

[47] However, because there are costs associated with adopting technologies that make it feasible to use higher frequency spectrum (expanding the range of useable RF) and to facilitate more intensive use of existing usable and allocated spectrum (*e.g.,* spectrum sharing), these could be thought of as investments in increasing spectrum "capacity." However, these costs are *not* directly associated with using the spectrum but rather with how it is used. A good spectrum management regime will provide appropriate incentives for adopting such technologies.

[48] Interference management involves both the allocation of scarce spectrum when multiple uses cannot share the spectrum, and coordinating usage so that when sharing can occur, it does so without inflicting damaging interference on each other. There are many ways to manage such coordination. For example, it could be on the basis of a "first come, first serve" where other uses wait until the channel is clear; or it could be based on changing the modulation scheme or operating frequency; or on some other approach. Whatever approach is adopted, it may impose some costs on one or more of the users (*e.g.,* late comers are delayed or everyone tolerates a noisier environment), however the expectation is that costs associated with operating an efficient shared use coordination mechanism will be small relative to the value of the traffic coordinated. While there may be some adoption costs (*e.g.,* higher cost for software or equipment to implement the sharing mechanism), any recurring costs per user will be negligible.

[49] A similar debate occurred over whether Internet access is "free." Traditionally, the heaviest users were university researchers and corporate employees. End-users did not directly pay for using the Internet and so perceived that there were "no usage fees." However, the costs of supporting the infrastructure were borne by the universities and corporate employers who paid flat monthly fees based on the capacity of their connections to the Internet. These capacity charges were correlated with usage (larger pipes for more traffic) and were sometimes subsidized (government funding for the Internet) (see McKnight and Bailey (1998).

[50] Of course, with flat rate pricing for blocks of calls, the monthly rate stays the same as long as the caller does not exceed their allowance. Customers who expect to make more calls, select a higher price bundle.

[51] The public benefited from the use of the services that could be lower priced because they did not have to recover the cost of acquiring spectrum. For example, the first mobile license was given to the incumbent telephone carriers and the second was awarded via lottery. The reasons why it is undesirable to use auctions to extract scarcity rents for using spectrum are discussed further below.

[52] There is no material difference in charging for spectrum use of "dedicated unlicensed" via a license fee for the intellectual property associated with a protocol that is approved to operate in the spectrum and via charges for a service that is only available via "licensed spectrum."

[53] See Hazlett (2001) for a discussion of the many examples where incumbents have resisted spectrum reform that would have alleviated regulatory-induced scarcity by allocating additional spectrum for potential competitors.

[54] That is, unlicensed use does not mean use without any rules. The unlicensed spectrum may be managed by a protocol that provides a technical determination of how spectrum will be allocated during periods of congestion.

[55] Ting, Bauer, and Wildman (2003) cite the costs of clearing unlicensed PCS spectrum (U-PCS) that were collected in device fees for qualifying equipment seeking to use the asynchronous allocation as a potential explanation for why this spectrum remains under-utilized.

[56] That is, if bidders are participating in a sequential auction, the truth-revelation properties may be different. Bids may be reduced to reflect the fear that future government policies will seek to capture some of the profits anticipated by bidders.

[57] See Crampton (2002), McMillan (1994), or Rosston and Owen (2002) for examples of economist support for spectrum auctions. For a contrary view, see Noam (1995) or Melody (2001). Theoretically, a bidder should not bid more for the spectrum than what the spectrum is worth to the bidder after accounting for the expected costs of constructing the network that will use the spectrum and the other costs of operating the business. Once the spectrum is acquired, it is a sunk cost and as long as capital markets are efficient, the bidder should still have the same incentive and opportunity to deploy its network. Unfortunately, capital markets are unlikely to be efficient as the capital shortages faced by telecom firms during the recent downturn in the sector demonstrated. Additionally, expectations may be incorrect and the winner's curse may apply.

[58] That is, in principle, an auction and a lottery followed by secondary market trading will both assign spectrum to its highest value use. In practice, this need not be the case since neither the initial auction nor the subsequent trading may be efficient for reasons discussed further below.

[59] Kwerel and Williams (2002) recommend that the government be required to bid for spectrum that might be set aside for dedicated unlicensed use.

[60] For example, restrictive licensing rules can limit the extent to which services operating in different frequencies can compete with one another.

[61] See Rothkopf and Bazelon (2003), Melody (2001), and Noam (1998) for critiques of using auctions to extract surplus.

[62] See Peha (2003) for a description of how such a system might operate.

[63] See *FCC Interference NPRM ET03-237 (2003)*

[64] Primary use is consistent with government pre-emption under special circumstances. The need to have adequate spectrum available in the case of an emergency or for national security is often cited as a reason for why additional government spectrum should not be released for commercial use. One solution to this is to provide for government-preemption or interruption during such periods. If necessary, such pre-emptible

service could be provided for spectrum allocated via exclusive licenses or dedicated unlicensed and so need not provide a basis for preferring an exclusive licensing regime.

[65] There should not be usage charges that require a service provider agreement. Therefore, if there are costs these should be capitalized in the price of the radio equipment and, in any case, are expected to be minimal per end-user.

[66] This rough estimate was provided by Carl Panisik, Texas Instruments, in the context of pointing out that spectrum costs would need to be much lower in order to make the high data rate services anticipated by 3G/4G services viable. To offer higher data rates, carrier's either need more spectrum, likely incurring higher auction fees, or by using the spectrum they have more intensively, which means more (smaller) cell cites and higher infrastructure costs. (Mr. Panasik offered this estimate during his talk at a workshop on spectrum reform sponsored by the National Telecommunications Information Administration (NTIA) on December 9, 2003. While quite imprecise, it was interesting to note that no one in the room of academics, government, and industry experts questioned the relative magnitude of this estimate.)

[67] Theoretically, it is possible to use the auction proceeds to offset *ex post* monopoly pricing to the extent that is desired (see Loeb and Magat, 1979).

[68] One may ask question whether a license-induced monopoly is a bad thing. There are two circumstances when economics suggests it might not be: (1) when the services to be provided via the spectrum are a natural monopoly (*i.e.,* costs are lowest when the market is supplied by a single provider); or (2) when the monopoly profits may be viewed dynamically as Schumpeterian returns to risky investments in an earlier period. In light of the trends in wireless services and competition elsewhere in telecommunications services, spectrum licensing is unlikely to be justified via recourse to a "natural monopoly" argument. The second argument relates to the potential need for licenses to provide efficient investment incentives, which is addressed further below.

[69] The equilibrium price will depend on both supply and demand conditions. In any case, expanding supply will mean prices will be lower for whatever level of demand prevails.

[70] See Johnston and Snider (2003).

[71] See Landler (2003).

[72] In the context of spectrum pricing, "over-provisioning" amounts to adopting technologies to expand the usability of available spectrum, which includes technologies that allow operation in increasingly noisy environments.

[73] See McKnight and Bailey (1998) for a summary of some of this research. See Odlyzko (1998) for argument that over-provisioning is less expensive than charging for quality-of-service.

[74] What constitutes efficient "pricing" depends on the context of the transaction. Pricing is inefficient if it precludes concluding buyer/seller transactions that would otherwise be efficient (*e.g.,* there are buyers with a willingness-to-pay that exceeds the cost of supply). In a competitive market, efficient pricing should reflect marginal costs; in a bilateral trade, any price between the buyer's willingness-to-pay and the seller's cost is potentially efficient. Prices are also inefficient if excess resources are expended in acquiring a price. In a competitive market, this may arise because it takes too long to settle on an equilibrium (market-clearing) price; in a bilateral trade, because there is too much bargaining.

[75] Because new technologies will experience network effects, scale and scope economies, and learning effects, it may be possible to foreclose emergence of a competing technology by denying it access to spectrum at affordable rates early in its life-cycle.

[76] That is, UWB would have to purchase rights to operate in the broad range of frequencies over which it spreads its signal. Purchasing such rights may be too expensive, precluding UWB participating in the market. The use of the spectrum by the carriers with ownership of the excludable licenses imposes a negative externality on the UWB technology that is not reflected in the prices for the excludable licenses.

[77] That is, when there are network effects, early adopters convey a subsidy on subsequent adopters because the value to every subscriber is greater when the network is larger. Such network effects can provide the basis for penetration pricing (*i.e.,* early adopters pay lower prices, which increase as the size of the network grows, see Katz and Shapiro, 1986). These may arise because the market needs to "learn" about the benefits of the new technology.

[78] A discussion of commons vs. private property management is beyond the scope of this paper. See Ostrom (1990), Benkler (1997), or Lessig (2001).

[79] See Konston (2002).

[80] Since nothing in life is certain or forever, the protection cannot eliminate risk and does not need to. Undertaking risky investments is a normal part of business.

[81] The license protects against *ex post* behavior that would threaten the *ex ante* expectation that the original investment will be recovered. This is analogous to the justification for granting intellectual property rights to provide incentives to invest in creating content.

[82] Denying access is not necessary. Merely increasing the cost of spectrum access to entrants or new technologies may be sufficient to block their entry in the presence of uncertainty, network effects, or scale economies.

[83] In addition to the references cited here, helpful information was provided by David Reed, Tim Shephard, David Clark, Marvin Sirbu, Jim Snider, Coleman Bazelon, Sharon Gillett, and Andrew Lippman, although they bear no responsibility for how I may have misunderstood them.